Integrated firn elevation change model for glaciers and ice caps

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1 BACKGROUND

What is the change in height by the densification of firn on glaciers and ice caps?

Geodetic elevation change measurements are a promising tool to derive high resolution mass balances of glaciers and ice caps. Up to now, geodetic mass balances inherit an uncertainty which occurs when converting geodetic volume change into glacier mass balance. The inaccuracy results from an inadequate conversion factor (density) which neglects altitude dependent firn density variations, firn layer thickness and not homogenous density variations with varying climate conditions.

To improve the accuracy of glacier mass balances measured in geodetic manner we develop a transferable firn elevation change model to minimize this systematic error. The main scope of the firn model are short term GMBs (3-5 yr) due to a high variability in the possible conversion factor[13].

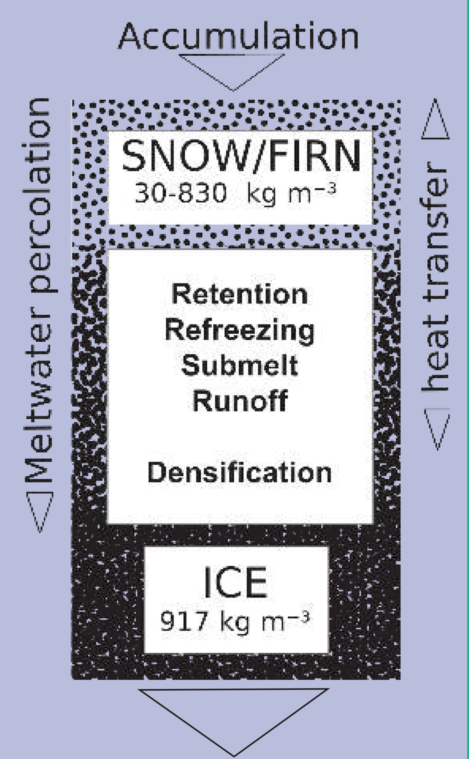
2 MODEL

The model is implemented in Python 2.7 and is based on a surface energy and snowpack model (COSIMA[5]).

Forcing: subdaily reanalysis (MAR[1]) data (**fig. a**):

- air temperature [K]
- incoming shortwave radiation [W m^{-2}]
- relative humidity [%]
- air pressure [hPa]
- wind speed [m s^{-1}]
- all-phase precipitation [m]
- cloud cover fraction.

Model concept:



Firn compaction [m]: $d\rho$

3 RESULTS

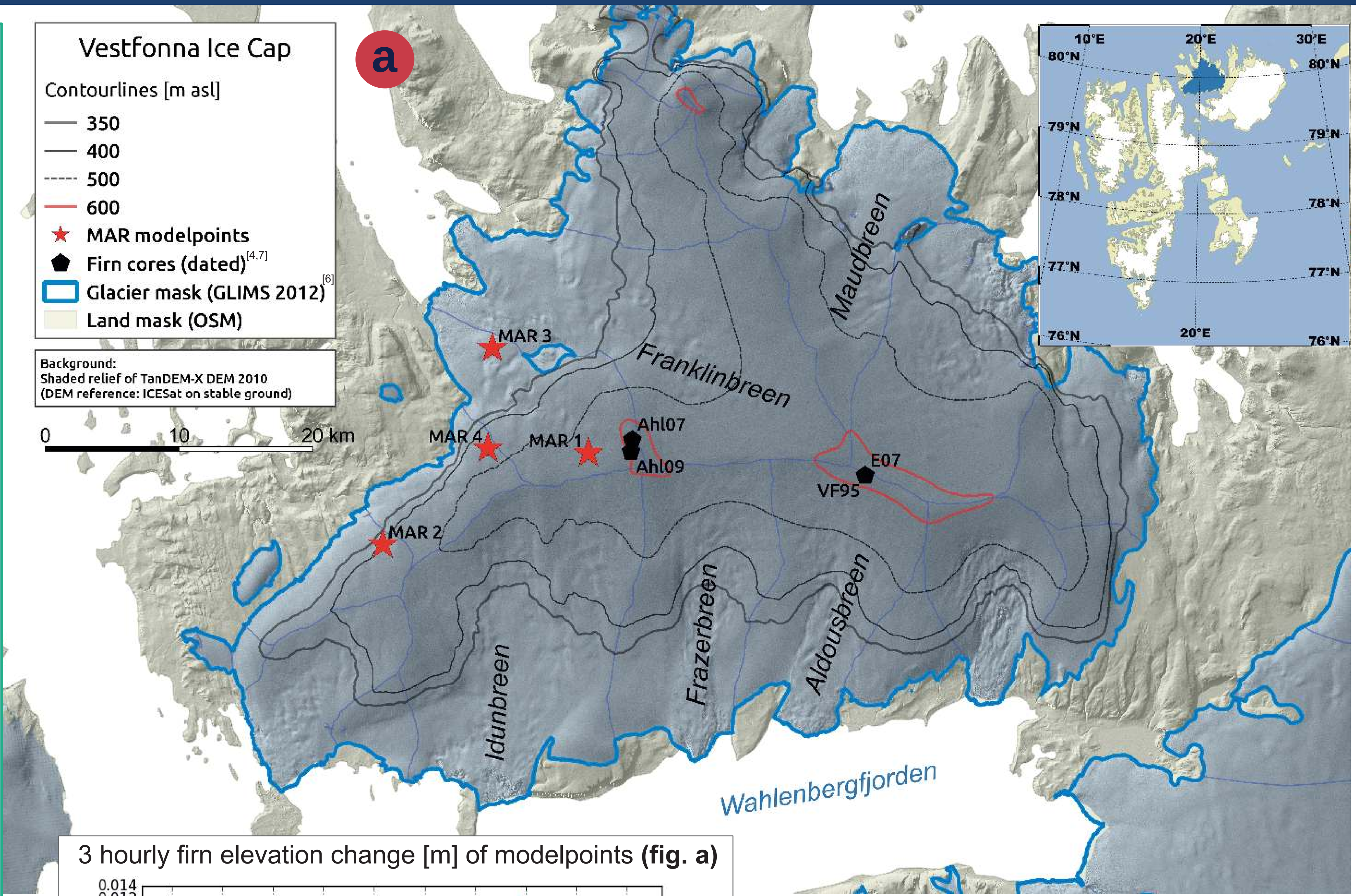
$$dM/dt = (dh/dt - d\rho/dt) * S * \rho_{ice}$$

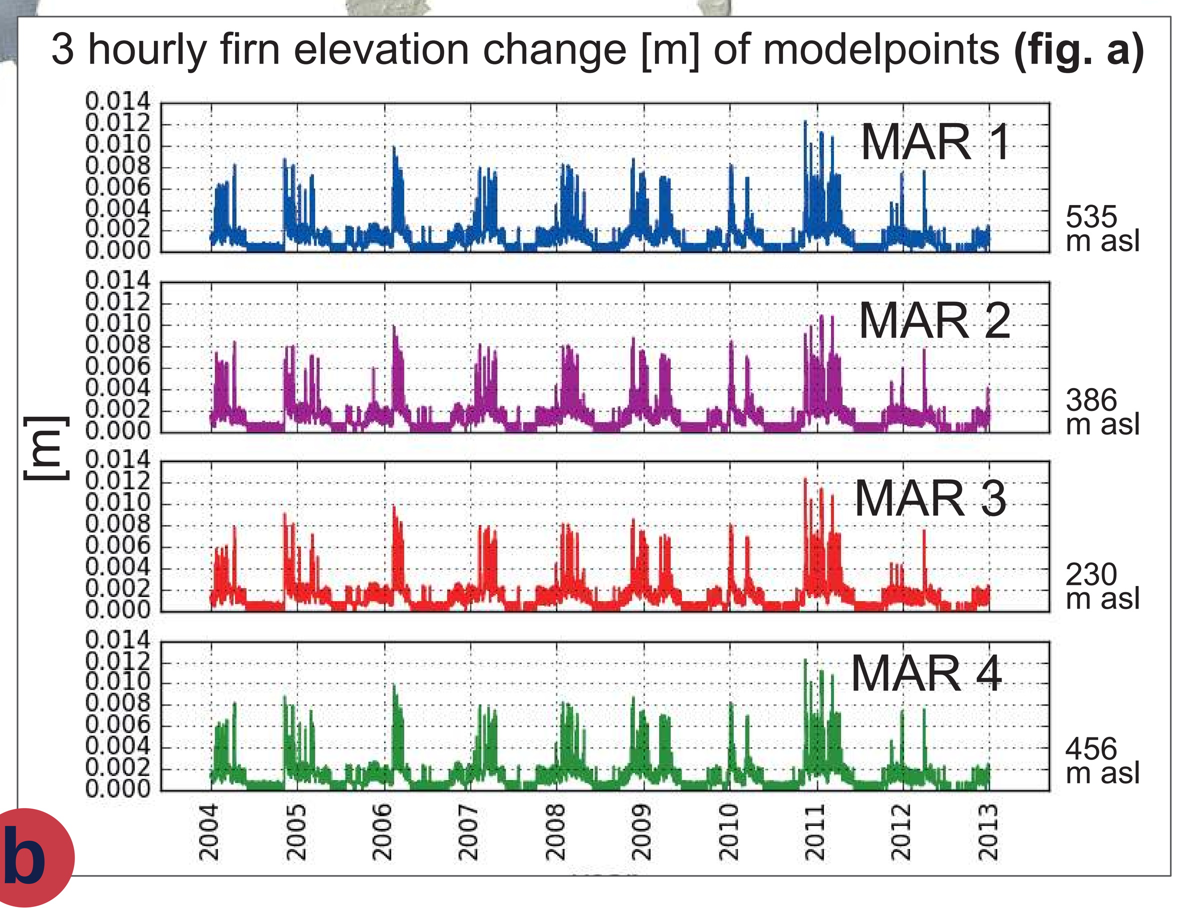
Exemplary model run:

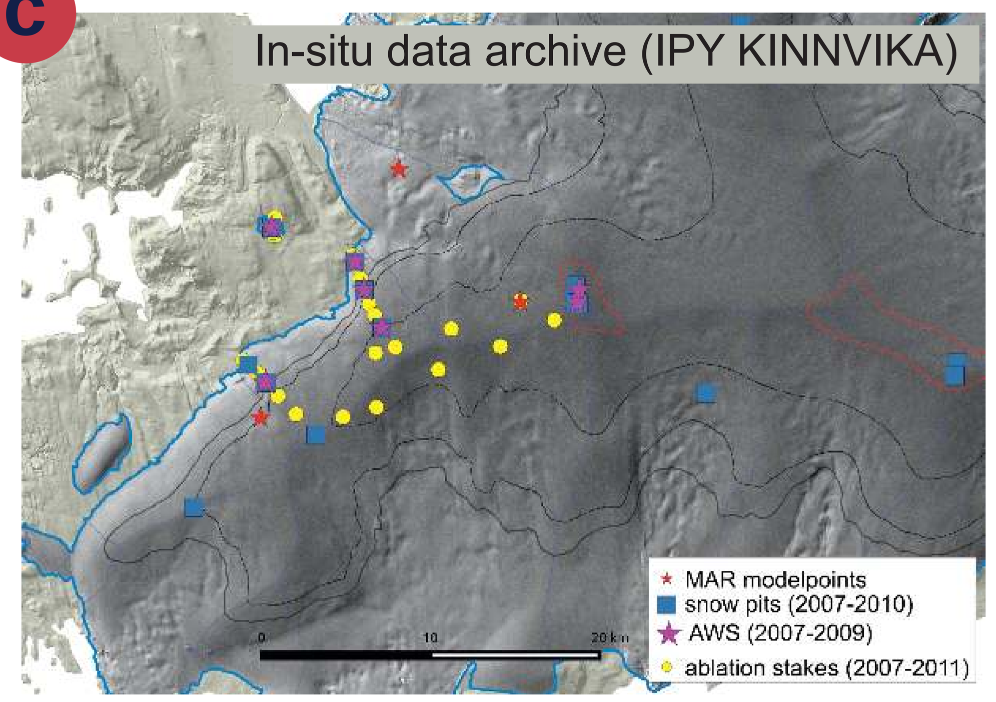
We selected four MAR modelpoints (**fig. a**) for a 9 year test phase, with 20 m depth, 0.5 m layer thickness, an idealized bottom temperature of -3.7°C[7] and one year spin up. **Fig. b** gives a brief overview about firn elevation change in meter. The firn evolution fits to the homogeneous snowpack pattern over the ice cap reported by Möller et al. (2011)[3].

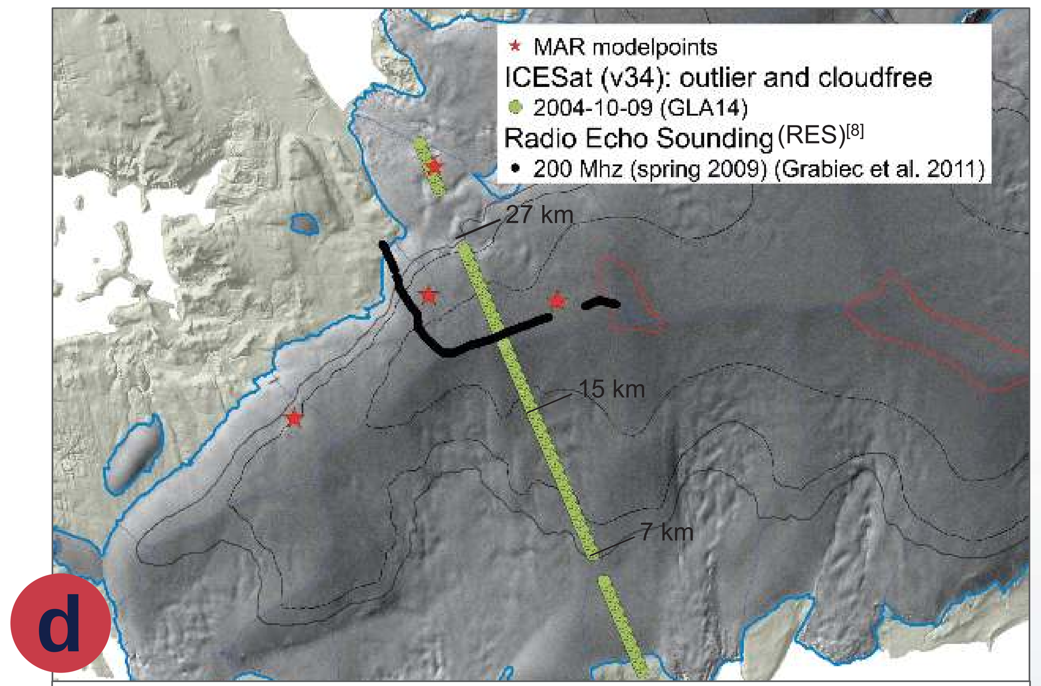
Geodetic measurements:

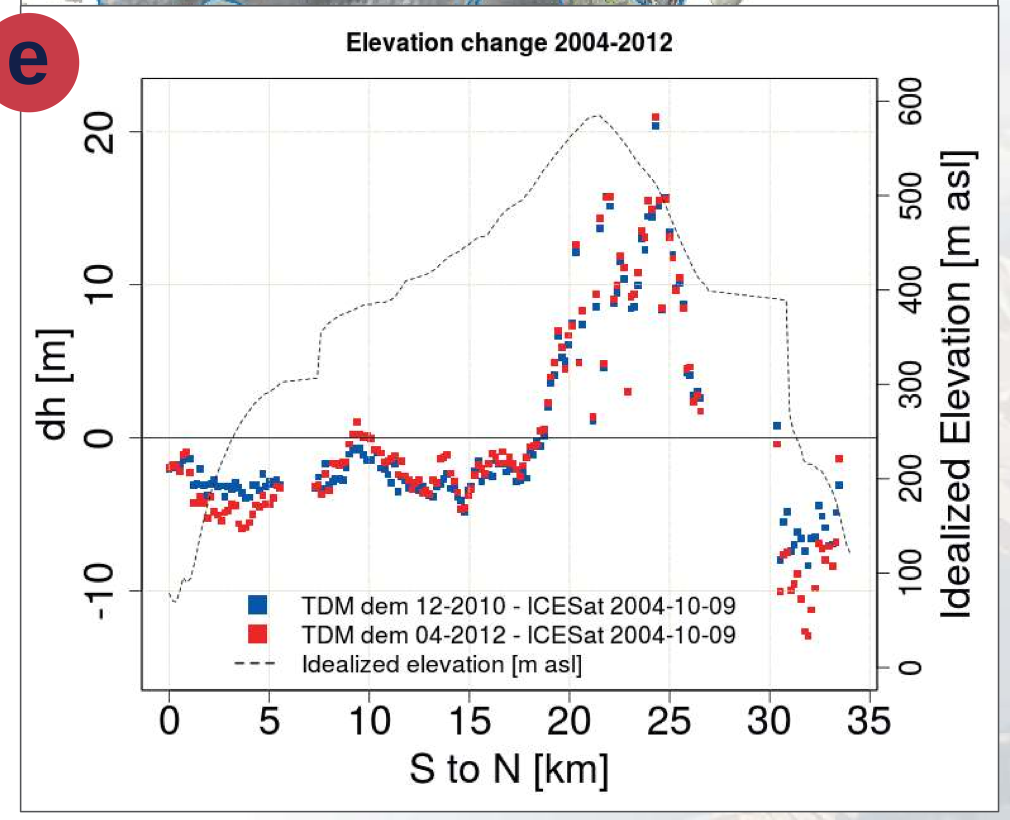
The second project part comprises an extensive analysis of the geodetic mass balance of the test site. **Fig. d & e** give a first impression on how the elevation of two TanDEM-X DEMs compared to one ICESat track (spring 2004) has changed between 2004 and 2012. The firn compaction signal is not yet removed, nevertheless, mind the thickening on the northwestern face of the ice cap (**fig. e**).











Acknowledgements:
TanDEM-X data provided under DLR AO XTI_GLAC0264 and XTI_GLAC6770. Glacier outlines are taken out of the Global Land Ice Measurements from Space (GLIMS) Glacier Database (http://www.glims.org/). ICESat elevation tracks are published by NASA National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC). CryoSat-2 data are postprocessed by V. Helm (AWI Bremerhaven). Detailed Info about IPY Kinnvika on http://www.kinnvika.net. We give thanks to Mariusz Grabiec and Marco Möller for in-situ data provision.

4 The test site

Vestfonna Ice Cap (VIC) (~2340 km^2) on Nordaustlandet, north east of Svalbard.

- Vertical spanning: 0 - 630 m asl
- Mean elevation: 386 m asl
- Mean ELA: 380 m asl (S ╲ N) [2]

The VIC is a polythermal ice cap with a dome like shape and gentle slopes. Most outlet glaciers calve into surrounding seas.

Melting can occur up to summit in summer season and mass balance year starts in September, with ablation period from June to August. [2]

The VIC showed almost balanced conditions in the last two decades, while the outlets were steady retreating, with the exception of the re-advance of the largest outlet glacier towards NW (surge). [2,10,11]

Firn thickness was 1996 10 m at summit [7], recent studies suggest it to be 15 - 20 m thick [4]. Melt water percolation and refreezing play a major role on the ice cap.

5 CONCLUSION

- For calibration and validation we have to run sensitivity tests against in-situ measurements (stakes (SMB)[2], snow pits (density & depth)[3], RES (stratigraphy)[8], firn cores (aging)[4]) (**fig. c**) to tune the parametrization.
- The elevation gain in the interior of VIC approve the observed accumulation increase in Northeastern Svalbard and a corresponding elevation increase uphill[11,14].
- TDM DEMs for Dec 2010 and April 2012 are ready, but they show no significant elevation change (signal is in error bar)! TDM DEM for 2015 is in process.

Abstract of resources:
[1] Lang, et al., 2015. Stable climate and surface mass balance in Svalbard over 1979–2013 despite the Arctic warming. Cryosphere 9, 83–101.
[2] Möller et al., 2011a. Climatic mass balance of the ice cap Vestfonna, Svalbard: A spatially distributed assessment using ERA-Interim and MODIS data. J. Geophys. Res. 116.
[3] Möller et al., 2011b. Snowpack characteristics of Vestfonna and DeGeerfonna (Nordaustlandet, Svalbard) – a spatiotemporal analysis based on multiyear snow-pit data. Geogr. Ann. Ser. A-phys. Geogr. 93.
[4] Beaudon et al., 2011. Spatial and temporal variability of net accumulation from shallow cores from Vestfonna Ice cap (Nordaustlandet, Svalbard). Geogr. Ann. Ser. A-phys. Geogr. 93.
[5] Huintjes et al., 2015. Evaluation of a coupled snow and energy balance model for Zhadang glacier, Tibetan Plateau, using glaciological measurements and time-lapse photography. Arct., Antarc., Alp. Res.
[6] Koenig, 2010. GLIMS Glacier Database. Boulder, CO. National Snow and Ice Data Center.
[7] Watanabe et al., 2001. Studies on climatic and environmental changes during the last few hundred years using ice cores from various sites in Nordaustlandet, Svalbard. Mem. Natl. Inst. Polar Res., Spec. Issue.
[8] Grabiec et al., 2011. Snow distribution patterns on Svalbard glaciers derived from radio-echo soundings. Pol. Polar Res. 32.
[9] Pettersson et al., 2011. Ice thickness and basal conditions of Vestfonna Ice cap, eastern Svalbard. Geogr. Ann. Ser. A-phys. Geogr. 93.
[10] Braun et al., 2011. Changes of glacier frontal positions of Vestfonna (Nordaustlandet, Svalbard). Geogr. Ann. Ser. A-phys. Geogr. 93.
[11] Nuth et al., 2010. Svalbard glacier elevation changes and contribution to sea level rise. J. Geophys. Res.115.
[12] Cuffey & Paterson, 2010. The physics of glaciers, 4th ed. Butterworth-Heinemann/Elsevier, Burlington, MA.
[13] Huss, M., 2013: Density assumptions for converting geodetic glacier volume change to mass change.
[14] Moholdt et al., 2010. Recent elevation changes of Svalbard glaciers derived from ICESat laser altimetry. Rem. Sens. Env. 114.

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